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JWST TECHNICAL REPORT

Title: The NIRISS Imaging Sensitivity Stability Monitoring Program	Doc #: JWST-STScI-009000 Date: 17 April 2025 Rev: -
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1 Abstract

I describe an analysis of the NIRISS Stability Monitoring calibration program, which obtains dithered images of the "JWST astrometric field" in the Large Magellanic Cloud (LMC) on a regular basis to track the long-term stability of the sensitivity of NIRISS with the F200W filter. The stability is measured by means of aperture photometry of relatively isolated stars within the Astrometric Field to determine their brightnesses as a function of time, and then using clipping statistics to derive overall median slopes of relative brightness vs. time. Over the time interval of July 2022 – March 2025, we find an insignificant time dependence of the F200W sensitivity of –0.14% ± 0.08% per year. This result is consistent with that of Volk (2024), who used an independent measurement methodology. The code and supporting files for this analysis are maintained on the NIRISS GitLab site and are run after each observation of the ongoing Imaging Stability Monitoring calibration program.

2 Observations and Data Reduction

Direct images are taken of the JWST Astrometric Field in the Large Magellanic Cloud near the south ecliptic pole, which is located in JWST's continuous viewing zone. These calibration observations are taken with the F200W filter on a monthly (in Cycle 1) or bi-monthly (in Cycle 2 and forward) cadence to assess the NIRISS system response over time by monitoring the stellar brightness values. The setup of the exposures is as follows:

Subarray	Pupil Wheel	Filter Wheel	Readout Pattern	NGROUPS	NINTS	Number of Dithers	Dither Pattern Type
FULL	F200W	CLEAR	NISRAPID	12	1	4	Imaging

The program IDs of these calibration observations are 1515, 4475, and 6655 in JWST cycles 1, 2, and 3, respectively. As of this writing, it is foreseen that this monitoring program will continue in subsequent cycles.

The analysis detailed below is performed on the Stage 2 products of the JWST imaging pipeline (i.e., the _cal.fits files). *It is strongly recommended to have all imaging datasets (re-)calibrated using the same pipeline build and the same reference files* before conducting the analysis described in Section 3.2 below. This avoids any systematics associated with the basic reduction steps in the calwebb_detector1 and calwebb_image2 pipeline stages.

3 Analysis

3.1 Creation of Source Catalog

Since the orientation of the JWST focal plane relative to celestial north rotates during its orbit around the Sun and we wish to obtain brightness monitoring of each star in the catalog every month, the goal is to create a catalog of sources that is always in the field of view. While this excludes a portion of the instantaneous NIRISS field of view, this does not present a problem since the astrometric field contains several thousand stars useful for this monitoring.

To create a source catalog with sky coordinates in the GAIA DR3 reference frame, we run jwst.pipeline.Image3Pipeline to create a combined, resampled image from all 12 visits of program 1515 (i.e., 12 * 4 = 48 _cal.fits images). To this end, we used several non-default settings in the tweakreg step as detailed below.

Before running Image3Pipeline, we created custom-made star catalogs for each individual input _cal.fits image using photutils.detection.IRAFStarFinder. This detection class was used instead of the default DAOStarFinder one because the latter algorithm leads to centroids that are regularly off by up to 0.6 pixel due to the undersampled point spread function (PSF) of NIRISS in the F200W filter, while the centroid error for IRAFStarFinder almost always stays below 0.1 pixel (see Goudfrooij 2022)[1]. After creating star catalogs with IRAFStarFinder, we eliminated all sources within 50 pixels of the locations of saturated pixels, thus avoiding spurious detections due to features such as diffraction spikes around bright stars.

Best results with Image3Pipeline were reached with the following non-default settings of tweakreg:

'snr_threshold': 50
'abs_refcat': 'GAIADR3'
'use_custom_catalogs': True
'tolerance': 0.5
'searchrad': 0.7

Furthermore, for the resample step, we fixed the 'crval' parameter to the CRVAL1 and CRVAL2 (or RA and Dec) values in the header of the first input image (i.e., Observation 1 of program 1515), and we fixed the 'crpix' parameter to the central pixel of the output image, whose size was chosen to be 2900x2900 pixels. All other parameters were kept at their default values. The resulting combined image (i.e., the _combined_i2d.fits file) is shown in Figure 1.

[1] As of JWST Pipeline build 10.2, the default detection class in the tweakreg step in the Image3Pipeline stage has been changed to IRAFStarFinder for NIRISS imaging.

To create the final source catalog for our monitoring analysis, we started out with the default catalog produced by the final run of Image3Pipeline. This catalog was cleaned using a function called "cleancat", which performs several selections: (1) it selects stars in the central part of the image which is always within the NIRISS field of view; (2) it determines the locations of pixels that were saturated in most input images, using information in the "context" extension of the combined image, and eliminates sources located within 5 pixels of those pixels; (3) it sorts sources on signal level, and then eliminates sources within 5 pixels of neighboring sources in the catalog that are brighter; and (4) it eliminates sources whose centroid location changes by 0.5 pixel or more after a re-centering routine using a 2-D gaussian fit, which indicates the likely presence of multiple stars within a few pixels (see Goudfrooij 2022). The final cleaned source catalog contains 2995 sources.

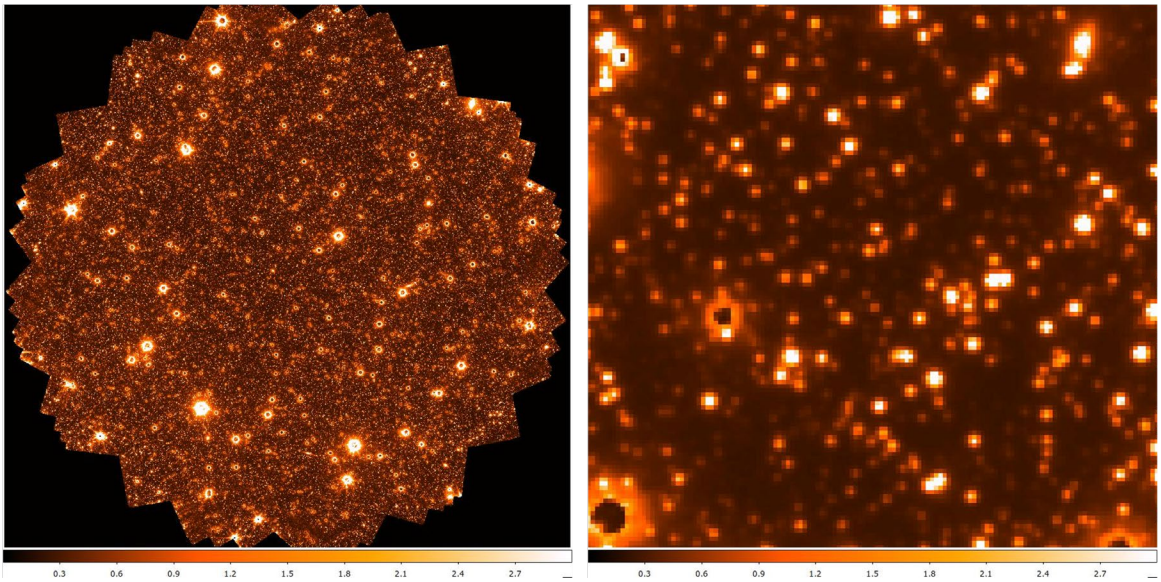

Figure 1: the left panel shows the combined image created from all observations taken as part of program 1515 (see text in §3.1). The size of the image is 190'' x 190''. The right panel shows a zoomed-in 9" x 9" part near the center of the image.

3.2 Monitoring Analysis

All steps of the analysis are performed by means of scripts and files that are available in the stability_monitoring_codes repository within NIRISS GitLab. The first step in the monitoring analysis is to determine offsets between the world coordinate system (WCS) of each _cal file of the first dither of an observation and that of the Gaia DR3 reference frame. This was done by translating (RA, DEC) in the source catalog created as mentioned above to (X, Y) of the _cal.fits file, using the model.meta.wcs.world_to_pixel function in jwst.datamodels.ImageModel. The (X, Y) locations of catalog stars are then compared to the actual locations of those stars in the _cal.fits file, and the approximate shift (ΔX, ΔY) is noted for each such file. These shift values only need to be accurate to ~3 pixels, since the subsequent analysis will perform appropriate re-centering for the catalog stars in each dithered exposure. Hence, if the shift distance is less than 3 pixels for a given _cal.fits file, it can be defaulted to (0, 0). With those shifts in hand, we call a function crowdphotdit4 which performs the following steps:

- For each target in the source catalog, translate (RA, DEC) to (X, Y) and re-center. This is done for each of the (4) dithered exposures of a given observation.
- Determine background level for each of the dithered exposures. This involves calls to function get_crowded_bkgval which is dedicated to determining background levels of images with strong source crowding, which is done using a 3rd-order polynomial fit to the peak of the distribution of pixel values. This was found to be a relatively robust way to derive the mode and its uncertainty.
- In each dithered exposure, look for the presence of bad pixels (Data Quality codes 'DO_NOT_USE' or 'SATURATED') within a radius of 4 pixels around each source. If present, a flag is assigned to ensure that that star in that dithered exposure is not used in the determination of photometric stability over time.
- Perform aperture photometry in the original (non-background-subtracted) images. Photometric errors are also derived. At present, the default measurement radii are 2 and 3 pixels; two radii are used to evaluate the effect of differing wavefront errors between different observing epochs. The sky background level was taken to be the result of get_crowded_bkgval mentioned above.
- Inverse-variance-weighted averages of source signal levels are determined across all (4) dithers of a given observation, taking the bad pixel flags as derived above into account. Sources with "bad pixel" flags in all dithers are given a signal level of zero and a flux error of 9999.
- Finally, an output table is created for that observation, listing observing date as well as averaged photometry results for each source in the catalog. By default, the name of this table is determined from header information in the input _cal.fits file, and has the form "<visitroot>_<filter>_aver_<date_in_years>.dat". Example: jw04475009001_F200W_aver_2024.2163.dat.

After the above procedure has been run on all input _cal.fits files, a list file should be created that lists the names of all those tables with averaged photometry results for a given observing date. This list file is called "avertabs.lis" in the following. The stability analysis is then performed using analyze_stability.py as follows:

```
$ python analyze_stability.py avertabs.lis
```

This script runs through all sources in the input table(s) and determines the number of epochs during which that source has good photometry measurements. If this number is at least a certain minimum number (the current default is 5), then the following linear function is fit to the data for source i:

$$signal_i = a + slope_i * (OBSDATE - 2023.0)$$

where OBSDATE is the observation epoch in years. This is done for both measurement radii. After this is done for all sources in the catalog, a statistical analysis is done on the values for $slope_i$ (and their uncertainties) and $>3\sigma$ outliers are discarded in order to exclude sources like variable stars. The resulting weighted average slopes are written to output tables, one for each measurement aperture, with names "NIS_stability_2pix_<current date>.txt" and

"NIS_stability_3pix_<current date>.txt", as well as a list file called “stabilityfiles_<current date>.lis”.

Finally, plots of the results can be created by running the following:

```
$ python plot_stability.py -l stabilityfiles_<current date>.lis
```

This results in a matplotlib plot window as well as file “NIS_stabilityplot_<date>.pdf". The plot includes a legend stating the measured linear fit to the relative count rate as function of time since epoch 2023.0 as measured from all stars, after sigma clipping. Figure 2 shows this plot as created on Feb 26, 2025. The formal linear fit to the “slopes” (or relative count rates) as function of time is –0.20% ± 0.09% per year for the photometry with a radius of 3 pixels. The scatter around the best fit is dominated by the results for a few epochs for which relative count rates are lower than the fit by $\geq 3\sigma$. A comparison of the results of the photometry with measurement radii of 2 and 3 pixels shows that the deviation of the biggest “outliers” from the overall best fit are larger for the photometry with 2-pixel radius than those with 3 pixels, thus suggesting that the reason for those relatively low count rates is a relatively wide point spread function (PSF), due to a relatively large wavefront error of the primary mirror of JWST at those epochs. This is consistent with the results of Volk (2024) whose analysis was based on PSF-fitting photometry using Jay Anderson’s code `jwst1pass` (see Libralato et al. 2023), and found large wavefront errors at the same epochs. Re-doing the fit after excluding the epochs for which the relative count rates for measurement radii of 2 and 3 pixels differ by 0.5% results in a time dependence of –0.14% ± 0.08% per year (see Figure 3), which is consistent with that suggestion. We conclude that the current data indicate a decrease in imaging sensitivity with significance $< 2\sigma$.

4 Acknowledgments

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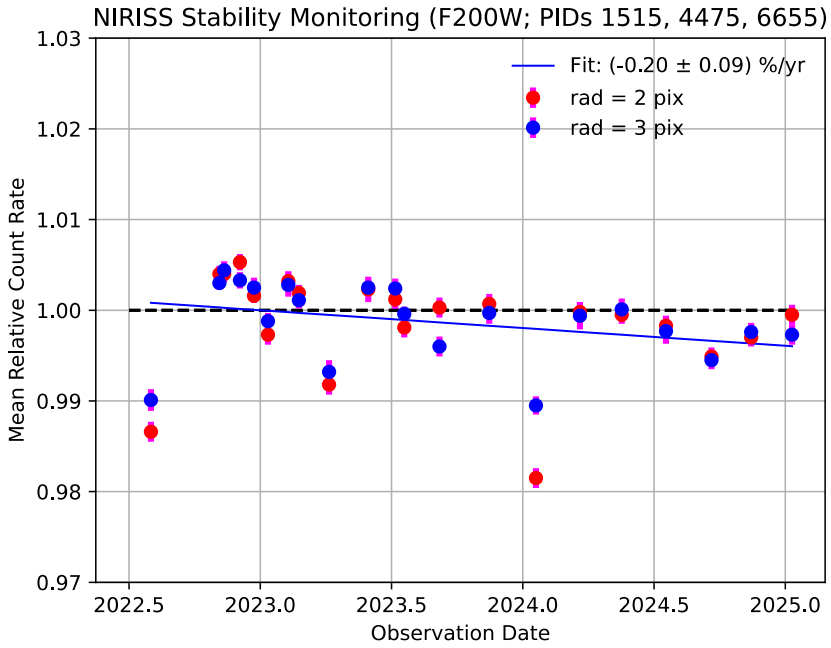

Figure 2: Median relative count rate as function of observing date for the stability monitoring program as of February 26, 2025. The red symbols represent the photometry for a measurement radius R = 2 pixels, while the blue symbols and line do so for R = 3 pixels. See discussion in the text.

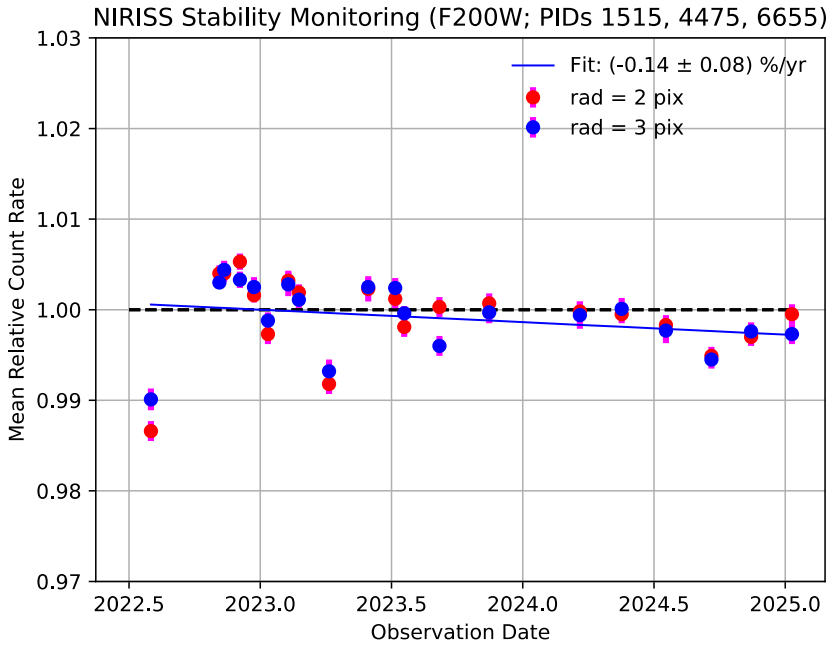

Figure 3: Same as Figure 2, except that the linear fits now exclude epochs for which the relative count rates for R = 2 and 3 pixels differ by 0.5% or more.

5 References

Goudfrooij, P., 2022, "Accuracy and Precision of Centroid Algorithms in the photutils Python package for NIRISS Point Spread Functions", STScI Technical Report JWST-STScI-008116 (Baltimore: STScI)

Libralato, M., Bellini, A., van der Marel, ,R. P., et al. 2023, ApJ, 950, 101

Volk, K., 2024, "Analysis of NIRISS Imaging Photometric Stability", STScI Technical Report JWST-STScI-008777 (Baltimore: STScI)